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DRAINAGE BY MEANS OF PUMPING FROM WELLS IN SALT RIVER VALLEY, ARIZONA

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INTRODUCTION

In the Salt River Valley of Arizona, as well as at a number of other places in the West, excessive irrigation, resulting in deep percolation, together with seepage from canals, has unfitted large areas for cultivation by reason of the raising of the ground-water level. These areas have increased rapidly in extent until corrective measures have become imperative.

Test borings in the Salt River project showed that about half of the project is underlaid by a coarse, water-bearing formation from which water may be pumped; and, as the Salt River Water Users' Association had available a large quantity of cheap electric power generated at its own plant, it was decided to install electric-driven pumps in wells located in the damaged areas to lower the ground-water level. This plan has been successful; water-logged land has been reclaimed; the rise of ground water in sections not yet damaged has been checked, and the pumped water has been used very largely to augment the supply available for irrigation.

The cost of the pumped drainage water does not exceed its value for irrigation purposes. The cost of development averaged approximately $2,900 per second-foot; and the average cost of labor, material, and power for pumping during the season of 1922–23 was about 40 cents per acre-foot.

The cost of the completed drainage system for the 203,000 acres of cultivated land in the project, including $75,115.19 for closed, gravity drains, was approximately $5.20 per acre; and the total cost of labor, material, and power during the 12 months preceding September 30, 1923, was 29 cents per acre.

Although the peculiar conditions of the Salt River Valley project were especially favorable to the operation, it is believed that a study of the results obtained in conjunction with the existing conditions will be valuable to those who may be confronted with problems similar to those successfully dealt with on this project.

THE NEED FOR DRAINAGE AND ADVANTAGES OF DRAINAGE BY PUMPING

The Salt River project, comprising about 203,000 acres of improved farm land, is located in south-central Arizona. With the exception of several abrupt, rocky protrusions, the Salt River Valley is a plain sloping gently toward the river. Salt River, which traverses the project for about 40 miles, and Agua Fria River, which flows along the western boundary, are in channels well below the general land surface and provide drainage outlets for all surface run-off.

The soils consist chiefly of sandy clay loam and loess underlaid by strata of clay and caliche (lime accumulations, either of soft character or firmly cemented) which vary from a thin layer to a thickness of 100 feet or more. In places these strata are underlaid by extensive deposits of gravel and bowlders (figs. 4, 5, 6, 7, 9, and 10). The top soil absorbs water at a moderately slow rate and holds it well. From two to four hours are usually required for a 6-inch application of water to disappear from the surface, and in low spots water may stand for several days before finally evaporating or sinking.

With the extension of irrigation, natural drainage outlets became overtaxed and the level of the water in the soil began to rise. According to yearly observations made by the United States Reclamation Service during 1913–1917, the water levels of 97 wells distributed through the valley showed an average annual rise of about 1.4 feet, and the area in which the water level was within 10 feet of the surface increased from 13,000 to 64,000 acres, and a portion of this area had become damaged by alkali.

Because of the relatively slow rate at which water can be drained from much of the soil of the valley and the thickness and depth below the surface of the water-bearing strata, drainage ditches of the usual depth have been only partially effective in ridding the surface soil of excess water. On the other hand, because of the great extent of coarse, water-bearing formation from which water may be recovered in large quantities by pumping, the low cost of electric power and the value of the recovered water for irrigation, the drainage of the water-logged areas by pumping from wells has proved feasible and profitable. This plan was adopted in 1918 by the Salt River Valley Water Users' Association, which operates the project, and at the close of the 1923 irrigation season 99 pumps were in operation. As a direct result, the area under which the water table was 10 feet or less from the surface, was reduced from 64,200 acres in 1918 to 17,662 acres in 1923. In practically all of the water-logged areas the ground water had been lowered sufficiently to permit of successful cultivation of the land. However, it is still somewhat higher than it was reported to be in 1903.

The possible disadvantages of the pumping method are largely economic. When the annual operating expense is high, as is likely to be the case, there is ever present a temptation to pump insufficient water to provide adequate drainage. Expert supervision and a high degree of mechanical skill are constantly necessary for the proper maintenance and operation of such a system and these are not always required for other purposes and might be prohibitive if water is pumped for drainage alone.

Quoting C. C. Cragin, general superintendent and chief engineer, Salt River Valley Water Users' Association:

> For small projects, a proper degree of mechanical skill might raise the cost of operation considerably above our cost. Our mechanical overhead is very low on account of our large power system. Pumps will not drain land unless operated and a tendency exists to save operating power costs unless constantly watched. The same applies to repairs. A pump shut down too long means damage to surrounding land. Daily operating records in the hands of the manager of the project are essential. In difficult drainage problems some experimentation will undoubtedly be required, and if the project is small this may become a serious item from the standpoint of public opinion as well as financially.
>
> In this valley we have not yet found a section which can not be more successfully drained by pumps than by any other method. This may be due and is at least undoubtedly affected by the high value to us of the recovered water and the cheap hydroelectric power owned by the project. It has, however, made possible a clear demonstration of the benefits and wide range of applicability of this method of drainage. For different conditions the economics of the problem may decide against drainage by pumps but, even where power must be purchased at commercial rates, the possibility of off-peak arrangements would suggest a thorough investigation of the pumping method before discarding it.

AREAS REQUIRING DRAINAGE

The principal areas needing drainage, in which is included all land having ground water within 10 feet of the surface, are indicated in Figure 1 as A, B, C, D, E, and F.

In the fall of 1918 when ground water in the valley stood at the highest recorded level areas A, B, and C formed a continuous strip extending from Phoenix westward along the north bank of Salt River to Agua Fria River and thence northward, comprising a gross area of 34,336 acres. The three areas constitute the low-lying project lands north of Salt River into which descends the drainage from the large irrigated area on the north and east. The land has a uniform southwesterly fall of from 10 to 15 feet per mile. As may be seen from profiles 1, 2, 3, and 4, of Figure 3, drainage outlet for both surface and subsurface water is afforded by Salt and Agua Fria Rivers. The tracts are similar in surface characteristics but there is considerable variation in the character and position of underground formations.

Area A, as shown by the logs of 17 deep wells (figs. 1 and 4 and Table 1), is underlaid by strata of clay, caliche, and water-bearing gravel and bowlders. The latter formation increases in thickness as Agua Fria and New Rivers are approached, indicating that these strata are contiguous to the gravel and bowlders forming the river bed. The average depth from the ground to the coarse water-bearing formation is a little more than 15 feet.

Area B (fig. 5) is underlaid by more fine material than is the case with area A. The logs of 10 deep wells drilled in this area show coarse water-bearing materials within 250 feet of the surface in strata little more than half as thick as and at greater depths than those in area A, but, as will be shown later, these differences have little or no effect on the yield of wells.

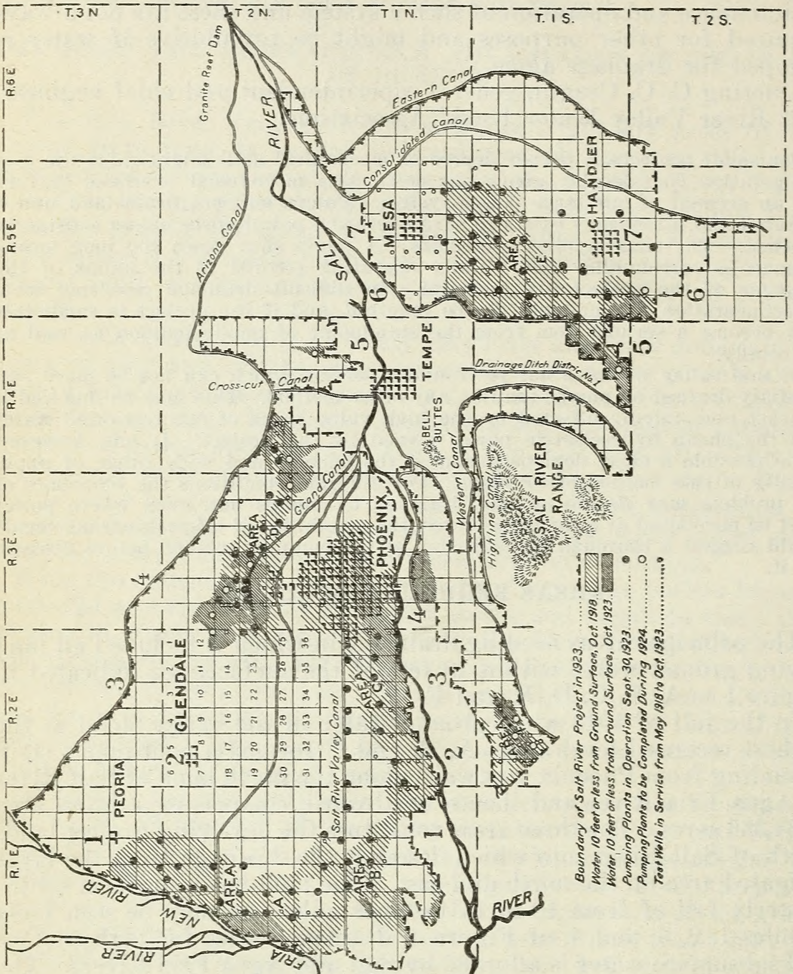


FIG. 1.—Map of Salt River Valley

Area C represents most favorable conditions for drainage by pumping from wells. A strip at least 7 miles long and in places 3 miles or more wide, on the north bank of Salt River, is underlaid by a great bed of coarse water-bearing gravel and bowlders known to be more than 150 feet thick in places. This extensive underground reservoir affords a place for seepage water to accumulate from the surrounding tighter formations, and thus makes the recovery of water by pumping from wells unusually effective and economical. According to the logs of the 14 deep wells shown in Figure 6, gravel and bowlders are present through most of the first 200 feet below ground surface. The average depth at which coarse water-bearing material is encountered is 31 feet.

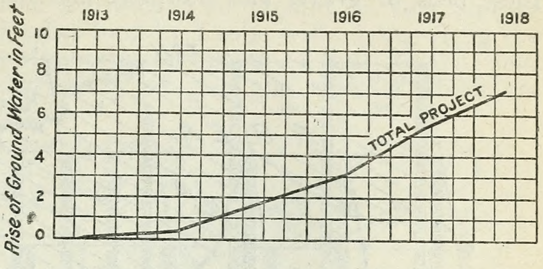


FIG. 2.—Curve showing rise of ground water in Salt River Valley, Ariz., 1913 to 1918

Area D offers one of the most difficult of the drainage problems of the project. The tract, comprising approximately 9,662 acres, is north and east of Phoenix, well away from any of the natural stream beds, and includes the valley's higher lands. Figure 3, profile 4, shows the positions of the ground surface and the water level. At the extreme eastern end is an area of about 500 acres where seepage water apparently travels along the slope topping rock, clay, and caliche strata, a condition which should favor the use of intercepting gravity drains. This is one of the two places in the project where gravity drainage was attempted, but the result was disappointing, and a final decision as to how to handle the problem has not yet been reached. Elsewhere in area D the ground water is evidently supplied by seepage from canals and irrigated fields with no marked single source. It is apparent from drilling records of 24 deep wells (fig. 7 and Table 1) that any drainage water developed in this area must come chiefly from caliche and other fine materials.

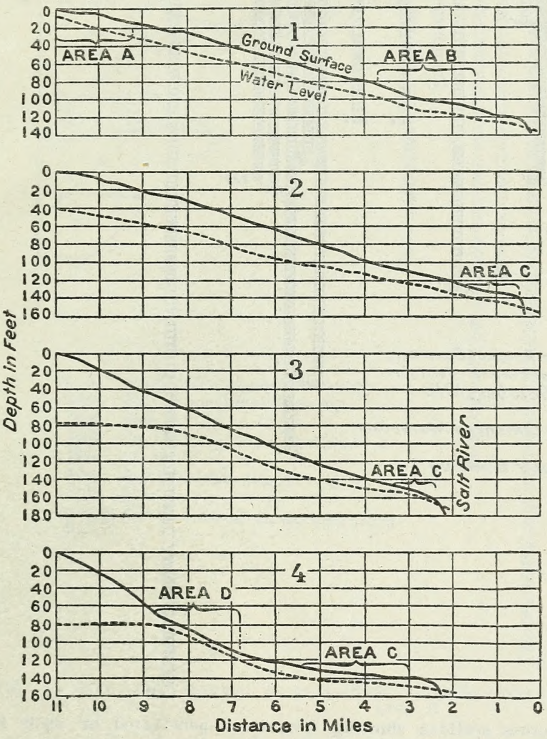


FIG. 3.—Profiles of ground surface and water levels on north side of Salt River project, Arizona

Area E is on the south side of Salt River south of Mesa and west of Chandler. Like area C it is underlaid by extensive beds of water-filled gravel and bowlders. It covers a gross area of approximately 17,252 acres. The rocky dike that once turned the river has for many years diverted the underflow of Salt River above Tempe into these beds of gravel and bowlders and has kept them filled with water, until surface flows appear in the restricted channel of Salt River at Tempe and along the slope leading down to Gila River east of the Salt River Mountains. Recent contribution to this ground water by seepage from canals and irrigated fields raised its level until in 1913 these lands became affected by a high ground-

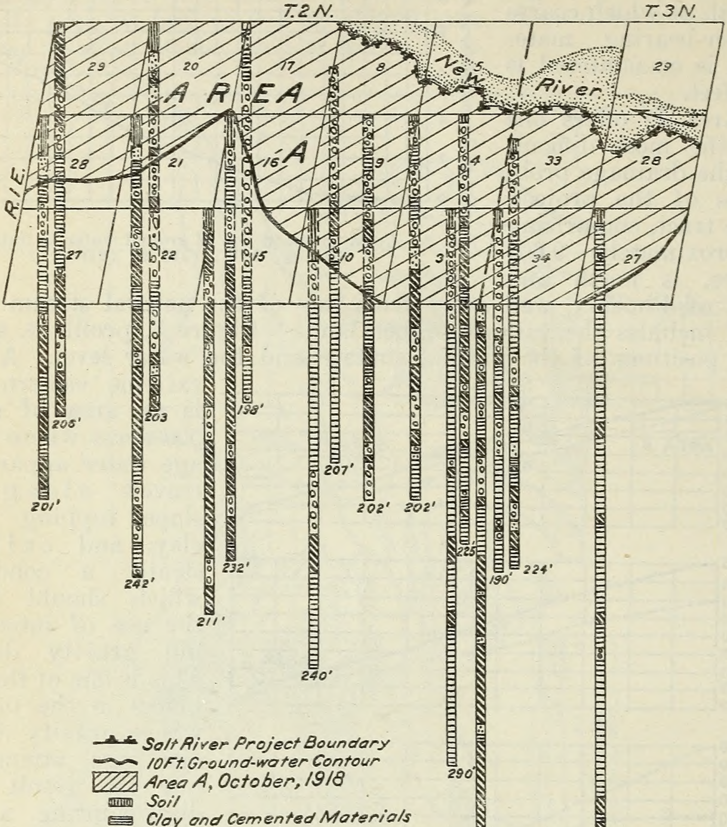


FIG. 4.—Map with vertical cross sections showing formations penetrated by wells in area A

water level. Profiles of the land surface and water table for this area are shown in Figure 8. Underground formations as indicated by the logs of 29 deep wells are shown in Figure 9 and in Table 1.

Area F, considered from a drainage standpoint, is very similar to area D. It is about 3 miles long by 1 mile wide, lying along the north side of Salt River Mountains and south of Salt River. Subsurface formations consist chiefly of clay and caliche, which are occasionally broken by thin layers of sand and mountain wash through which ground water percolates slowly. The logs of the two wells in Figure 10 illustrate this condition. The tract is of interest in this investigation chiefly because an attempt to relieve the high ground-water condition by means of a closed gravity drain has not been successful, and the plan of pumping from wells is being used to bring about a further lowering of the ground-water level.

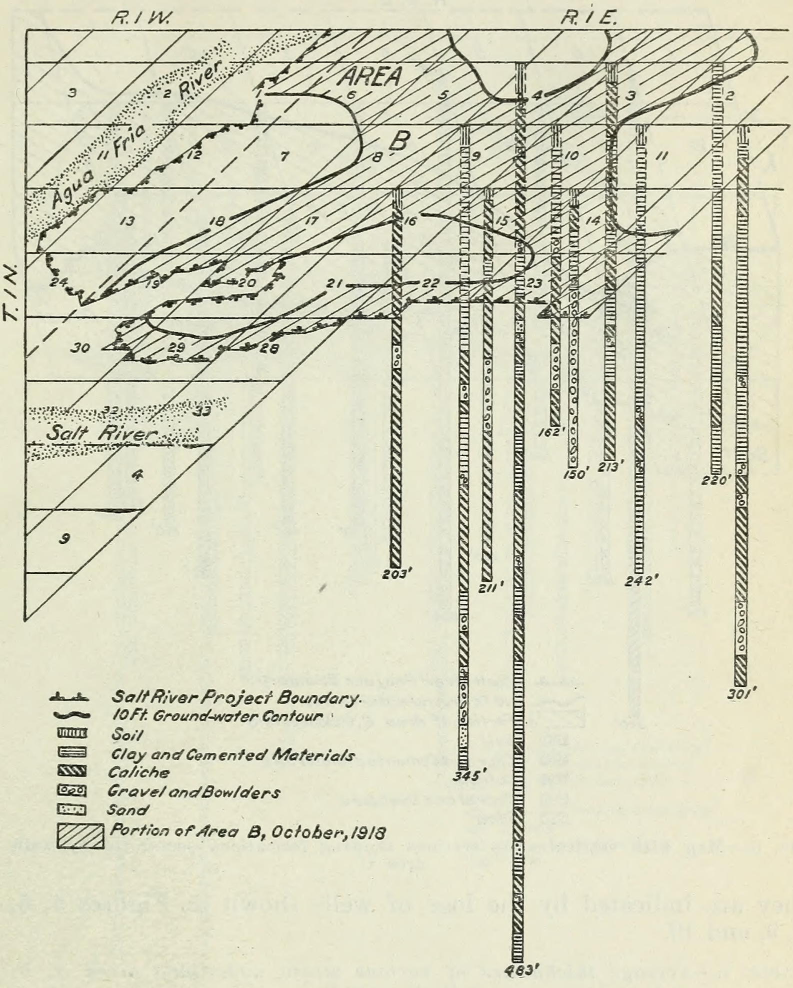


FIG. 5.—Map with vertical cross sections showing formations penetrated by wells in area B

There are several other tracts in the project where water is close to the surface, but these are small and of little importance, and will not be described in this bulletin. Their locations are shown in Figure 1.

Table 1 shows the average thicknesses of various materials underlying the surface of the six principal areas requiring drainage, as they are indicated by the logs of wells shown in Figures 4, 5, 6, 7, 9, and 10.

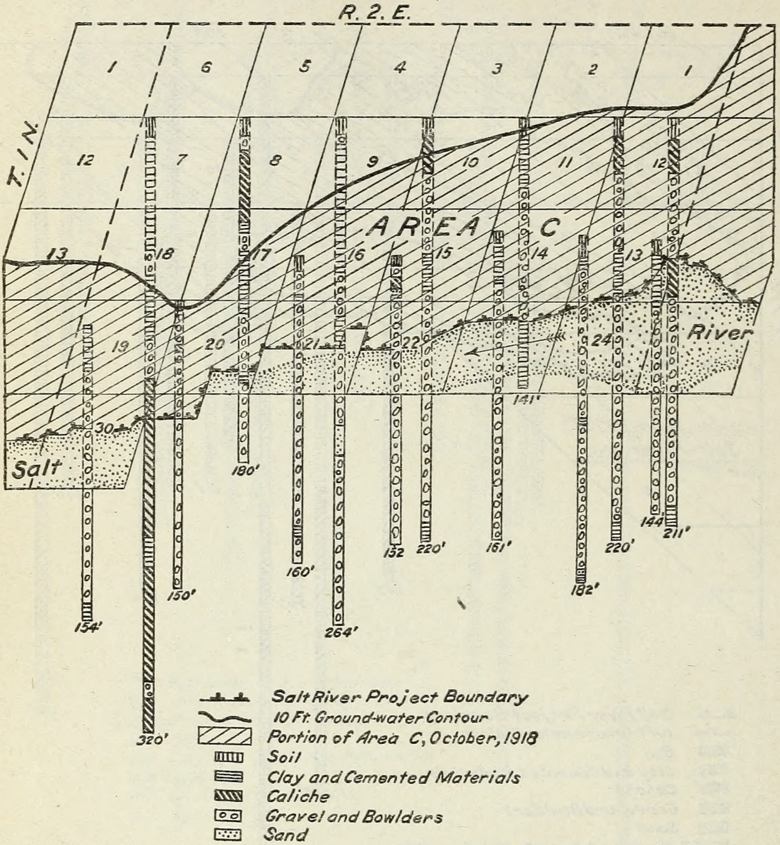


FIG. 6.—Map with vertical cross sections showing formations penetrated by wells in area C

TABLE 1.—*Average thicknesses of various strata underlying areas A, B, C, D, E, and F*

Areas	Number of wells	Clay, and cemented materials	Average thickness of soil		Gravel and bowlders	Average depth of well
			Caliche	Sand		
		Feet	*Feet*	*Feet*	*Feet*	*Feet*
A	17	95	67	7	66	235
B	10	110	105	3	35	253
C	14	38	23	2	127	190
D	24	154	72	3	12	241
E	29	61	17	3	120	[1] 201
F	2	136	58	0	7	201

[1] First 300 feet only of the 1,305 feet of McQueen deep well included.

THE DRAINAGE SYSTEM

According to present plans the completed drainage system will consist of pumping plants and wells; provisions for conveying pumped water; electric transmission lines, power to operate the pumps and short lengths of closed gravity drains in areas D and F.

In areas A, B, and C, 17, 10, and 14 drainage pumping plants, respectively, were in operation December 31, 1923. The total capacities of these pumps, according to ratings made in September, 1923, were 52.5 second-feet for area A; 28.5 second-feet for area B; and 59.0 second-feet for area C. It is not anticipated that additional drainage construction will be required. Placing of wells within these three areas at first (1919) was influenced by the location of irrigation canals into which pumped water could be discharged, but

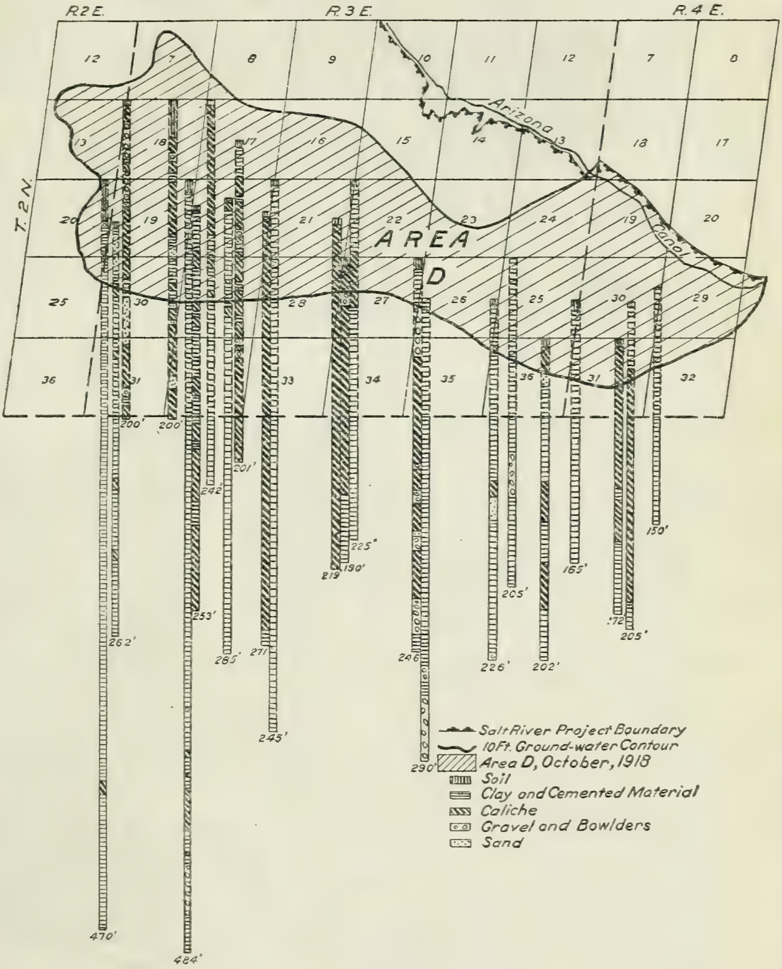


FIG. 7.—Map with vertical cross sections showing formations penetrated by wells in area D

more recently pumping plants have been installed closer to Salt and Agua Fria Rivers where the coarsest underground formations are found. The 41 drainage wells in these areas are 18 inches in diameter, cased with 10-gage, 2-ply steel casing liberally perforated to admit water below the 50-foot level. The average depth of wells and thickness of materials encountered are shown in Figures 4, 5, and 6, and are tabulated in Table 1. Pumps at each of the wells are of the pitless (deep well) vertical centrifugal type, electrically driven. All plants are housed in frame structures with concrete floors and are equipped with concrete discharge bays and weir boxes. An interior view and two exterior views of typical plants are shown in Plate 1. Sizes and makes, as well as other information regarding the various plants, are given in Table 4.

In area D, 18 wells and pumping plants with a total capacity of 20.5 second-feet were originally installed and two short sections of closed drains have been built. Six additional pumping plants of about 1 second-foot capacity each have since been added to the drainage system. Because of relatively poor underground conditions for recovering a large quantity of water from wells, drainage wells have been spaced closer together and pumping plants are of smaller capacity than elsewhere on the project. The general plan of construction and the type of equipment used has been the same as for areas A, B, and C, but the six pumping plants recently installed are less elaborate in design, and cost much less. This new type of small pumping plant is illustrated in Plate 2, B. Further information regarding wells and pumping plants in this area is listed in Tables 1 and 4.

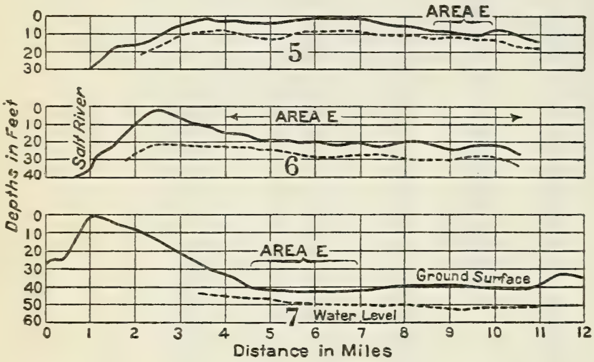


FIG. 8.—Profiles of ground surface and water level on the south side of Salt River Project, Arizona

The two closed gravity drains are located in section 29, T. 2 N., R. 4 E., at the extreme eastern end of the area. They consist of one line of 12-inch and one of 8-inch concrete pipe, each about 1 mile long and having an average depth of 11 feet. They lie at right angles to the direction of flow of underground water and at two different levels along the slope. Both discharge into cross-cut canal.

Area E has 19 drainage pumping plants and wells. Before 1918, eight other large plants were installed in or near area E to pump water for irrigation, and though not all located as favorably for drainage purposes as might have been wished, their operation directly affects the drainage situation; hence they should be considered as part of the drainage system. The total capacity of the 27 plants now in operation is 157.1 second-feet. Two more plants were put in operation during 1923 and 1924, and arrangements have been made to include in the Salt River project the high ground-water area adjacent to area E on the west and drainage pumps have been installed on this tract.

Construction features of the drainage plants are identical with those in areas A, B, C, and D. The irrigation plants installed before 1918 are electrically-driven vertical and horizontal centrifugal pumps drawing from batteries of two to five wells each. Housing of most of these plants is entirely of concrete, and motors and pumps are set in pits which are concreted down to water level. This type costs several times as much as the single-well type with deep-well pump, and for that reason was not used for the drainage installations. One of these irrigation plants is illustrated in Plate 2, A.

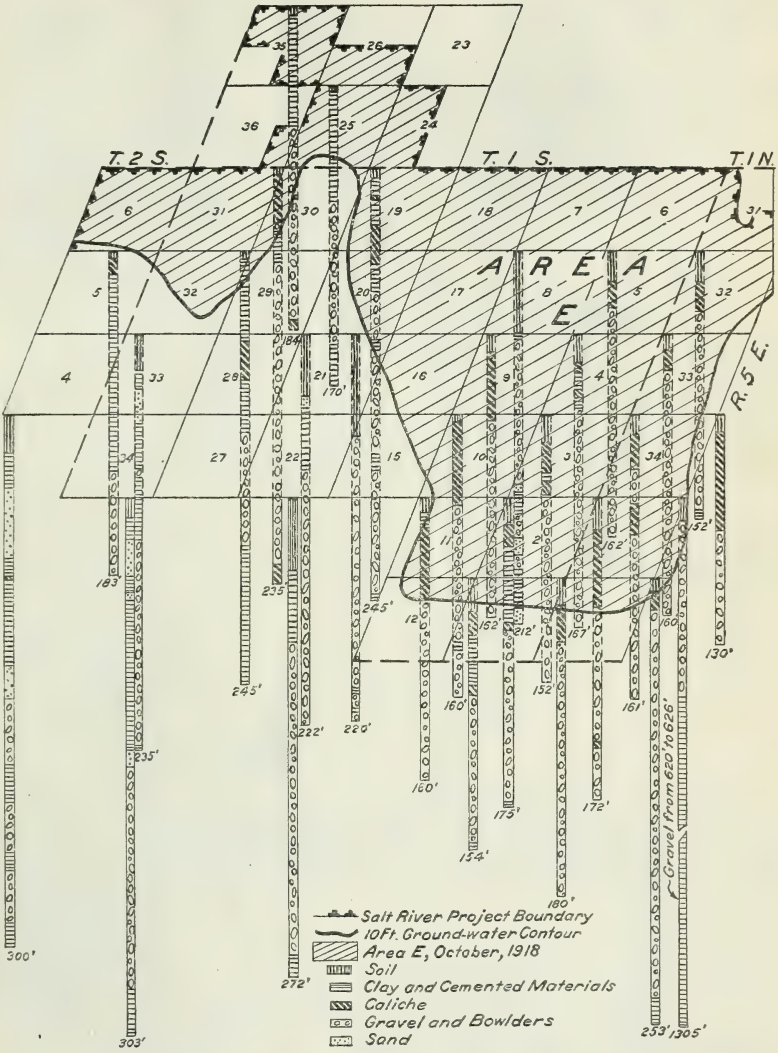


FIG. 9.—Map with vertical cross sections showing formations penetrated by wells in area E

Other information regarding pumping plants and wells in this area is given in Tables 1 and 4.

A closed gravity drain built between October, 1920, and September, 1921, was designed for relief of area F, but three drainage pumping plants have since been installed at the locations shown in Figure 1. The present gravity drain consists of 18,205 feet of 10, 12, 15, and 18 inch concrete and vitrified clay tile laid through the length of the area and at an average depth of 10 feet. From the boundary of the Salt River project the drainage water is carried through Salt River Indian Reservation in an open ditch. The capacity of the closed drain varies from 1 to 3 second-feet according to the size of pipe, but the actual discharge varies from 0 in winter to a maximum of 1.5 second-feet in summer. Its location with respect to the lands requiring drainage is shown in Figure 1. The drainage plants which were recently placed in this area are of the new type installed in area D. (Pl. 2, B.)

Power for operating all the drainage pumps is supplied by hydroelectric plants owned and operated by the Salt River Valley Water Users' Association. Because of the use of off-peak power for operating drainage pumps, only about one-fourth cent per kilowatt-hour is charged against the drainage system. This charge represents the average cost of maintaining and operating the power system during those periods when power is used by the drainage pumps. To a very large extent power that would otherwise be wasted is utilized for operating the drainage system, which accounts for the low power rate charged.

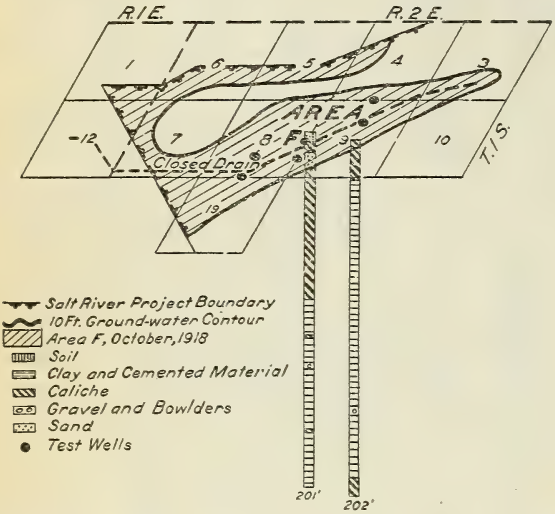


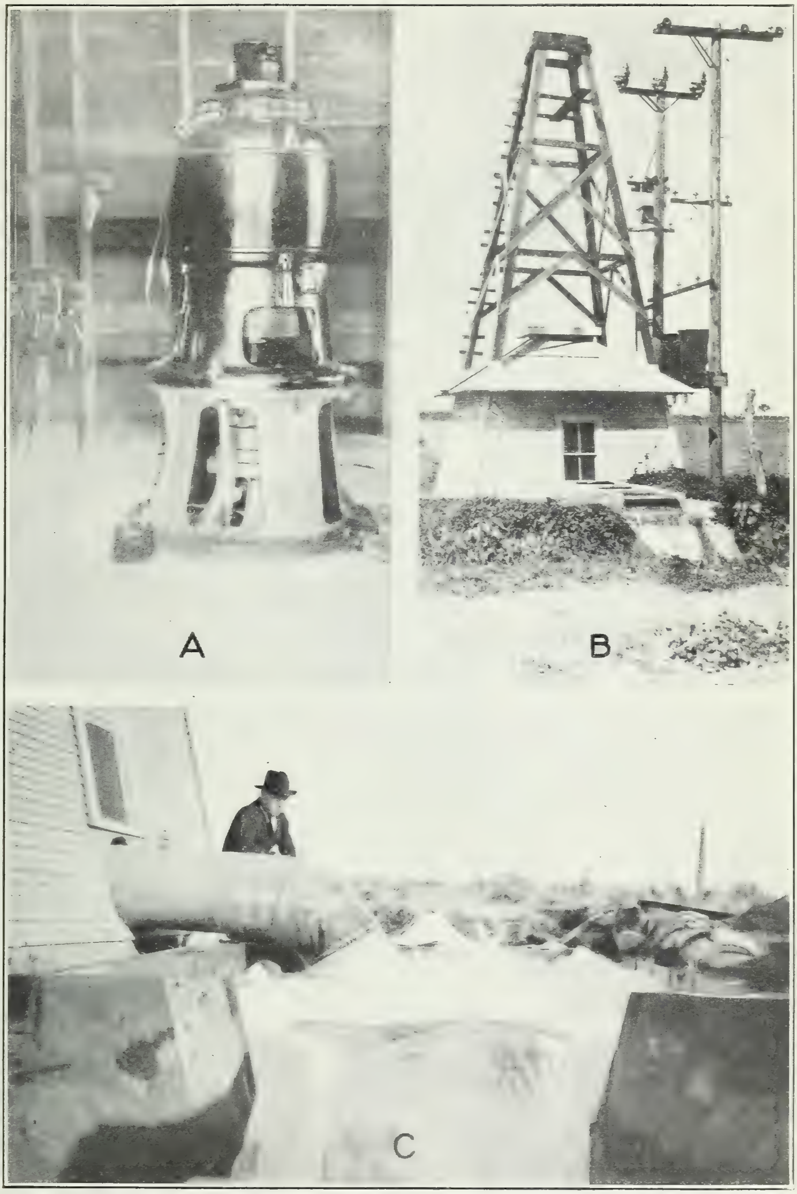
FIG. 10.—Map with vertical cross sections showing formations penetrated by wells in area F

In some cases pumping plants have been located close to existing irrigation canals and pumped water is discharged directly into them, but in many instances it has been necessary to make ditches of some length to dispose of it and this work has been carried as part of the regular drainage construction.

EFFECTIVENESS OF DRAINAGE BY PUMPING FROM WELLS

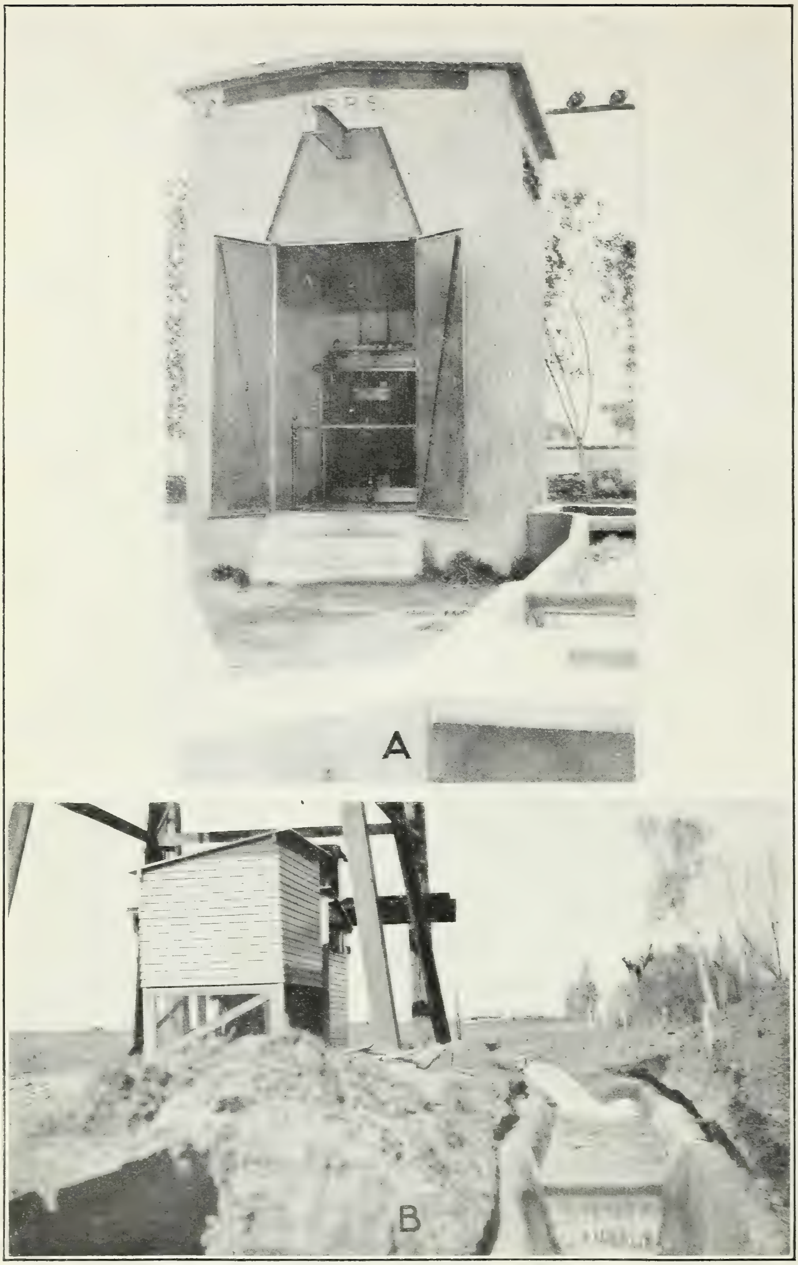
The efficiency of the drainage system has been ascertained by recording accurately the quantity of water removed from the ground and by noting the effect of this removal on water levels in the neighborhood of individual pumping plants and throughout the valley.

The running time of pumping plants has been kept to the nearest 15 minutes of their starting and stopping and the capacity of pumps



INTERIOR AND EXTERIOR VIEWS OF TYPICAL PUMPING PLANTS

PLATE II



PUMPING PLANTS IN AREAS D AND E

A.—Type of pumping plant installed before 1918
B.—New type of plant being installed in area D

has been determined frequently by means of readings over Cipolletti and suppressed rectangular weirs.

Regularly since 1913, observations of a great number of specially installed test wells have provided records of the fluctuations of the water levels. During the five years before commencement of work on the drainage system 97 test wells were observed annually to ascertain the rate of rise of the ground-water level. In 1918 this number was increased to 462 and observations were made thereafter in May and October of each year. In October, 1923, the most recent regular observation period, water levels were recorded at 834 wells.

The general effect of drainage is illustrated in Figures 1 and 11, which show the reduction of the area having water within 10 feet of the ground surface. Figure 12 shows fluctuations of water levels and quantities of water pumped from wells during six-month periods for the five areas where pumping from wells has been practiced. These curves are based on records of those test wells only for which complete semiannual water-level readings for the period 1918 to 1923 are available. Locations of these test wells are indicated in Figure 1. It shows a successive lowering of the water level in each of the five areas (A, B, C, D, and E) to a depth of 10 feet or more below ground in October, 1923. Table 2 lists the six test wells in each area having the highest ground-water level in October, 1923, and the location of each. At this time the water level had been lowered sufficiently to permit cultivation of the land over practically the entire area.

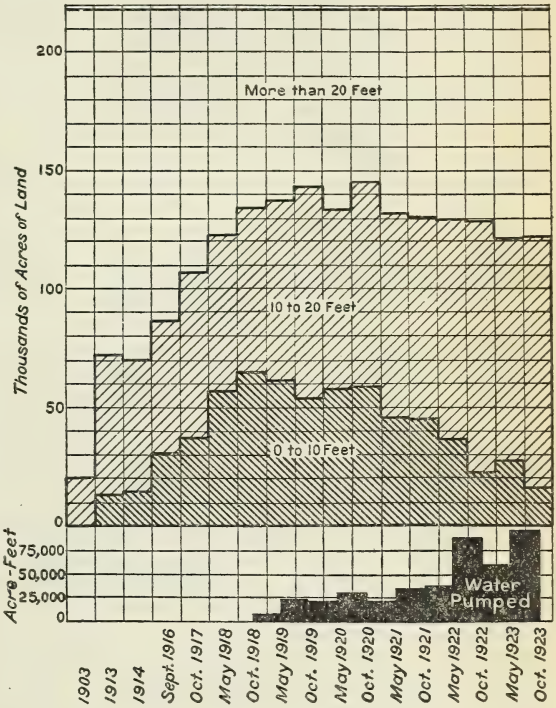


FIG. 11.—Total areas having various depths to ground water

All six test wells in area E are in the southeast corner directly in line with the underflow from a large tract of partially water-logged land lying without the project at the north. This portion of area E is therefore a difficult tract to drain, and although four drainage pumps are located in it, desirable results probably will not be realized until the adjoining area has been drained. On the remainder of area E the highest ground-water level in October, 1923, was 6.6 feet.

TABLE 2.—*Highest water levels occurring in areas A, B, C, D, and E in October, 1923*

Area A		Area B		Area C		Area D		Area E	
Location of test well	Depth to water	Location of test well	Depth to water	Location of test well	Depth to water	Location of test well	Depth to water	Location of test well	Depth to water
	Feet		*Feet*		*Feet*		*Feet*		*Feet*
NW. corner sec. 19, T. 2 N., R. 1 E.	6.7	NW. cor. SW. ¼ SW. ¼ sec. 28, T. 1 N., R. 1 E.	4.9	W ¼ cor. sec. 13, T. 1 N., R. 2 E.	6.4	SW. cor. NE. ¼, SW. ¼, sec. 21, T. 2 N., R. 3 E.	3.6	NW. cor. sec. 6, T. 2 S., R. 5 E.	3.0
SW. corner sec. 33, T. 3 N., R. 1 E.	8.8+	NE. cor. sec. 20, T. 1 N., R. 1. E.	6.8	SW. cor. sec. 15, T. 1 N., R. 2 E.	6.9	W. ¼ cor. sec. 28, T. 2 N., R. 4 E.	5.9	W. ¼ cor. sec. 35, T. 1 S., R. 4 E.	3.8
W. ¼ corner sec. 17, T. 2 N., R. 1 E.	9.3	NW. cor. SW ¼, NW. ¼ sec. 20, T. 1 N., R. 1 E.	7.0	SW. cor. sec. 18, T. 1 N., R. 3 E.	7.1	W. ¼ cor. sec. 17, T. 2 N., R. 3 E.	6.0	NW. cor. SW. ¼ SW. ¼ sec. 31, T. 1 S., R. 5 E.	4.1
W. ¼ corner sec. 20, T. 2 N., R. 1 E.	9.3+	W. ¼ cor. sec. 29, T. 1 N., R. 1 E.	7.9	S. ¼ cor. sec. 7, T. 1 N., R. 3 E.	7.5	NW. cor. SW. ¼ NE. ¼ sec. 21, T. 2 N., R. 3 E.	6.1	W. ¼ cor. sec. 31, T. 1 S., R. 5 E.	4.9
W. ¼ corner sec. 29, T. 2 N., R. 1 E.	10.5	NW cor. SW. ¼, NW. ¼, sec. 21, T. 1 N., R. 1 E.	8.7+	NW. cor. SW. ¼, NW. ¼, sec. 18, T. 1 N., R. 3 E.	7.8	Center cor. sec. 19, T. 2 N., R. 3 E.	6.1	NW. cor. SW. ¼, SW. ¼, sec. 35, T. 1 S., R. 4 E.	5.9
SW. corner sec. 31, T. 2 N., R. 1 E.	12.2	NW. cor. sec. 21, T. 1 N., R. 1 E.	9.0+	W. ¼ cor. sec. 14, T. 1 N, R. 2 E.	7.9	Center cor. sec. 29, T. 2 N., R. 4 E.	6.5	SW. cor. NE. ¼, SW. ¼, sec. 34, T. 1 S., R. 4 E.	6.3
Average	9.5−		7.4−		7.3−		5.7		4.7−

The influence of pumping from individual wells upon surrounding ground-water levels was ascertained in areas D and E, which represent the two extreme underground conditions met in the valley. Figure 13 shows the configuration of the ground-water level resulting from the operation of the drainage pump on the east line of section 20, T. 2 N., R. 3 E. This well was sunk to a depth of 285 feet entirely in clay and caliche (fig. 7). The capacity of the pumping plant is 1.5 second-feet. Draw-down of the water surface in the well during operation of the pump is about 60 feet. Curve *a* in Figure 13 represents the ground-water level just before the drainage pump was first started, and curve *b* shows its position after four months of pumping, during which 193 acre-feet of water were removed. The performance of this well while being pumped and the effect of its operation on the ground-water level show that clay and caliche do not yield large quantities of water readily; that drainage wells in such formations should be uniformly distributed at intervals of probably not more than one-half mile; and that only pumps of small capacity will be required.

Figure 14 shows the effect on the water table of the operation of the drainage pump located at the northeast corner of section 11, T. 1 S., R. 5 E. The coarse gravel and bowlder formation which extends throughout nearly the entire 154 feet of the well's depth is shown in Figure 9. The draw-down of the water level in the well while being pumped at the rate of 3.5 second-feet is 8.2 feet. Curve *a*, Figure 14, represents the ground-water level before pumping and curve *b* the level attained after the removal of about 373 acre-feet of water from the soil during a period of four and one-half months. Although the quantity of water which may be recovered from a single well of this type is fairly large, the resulting draw-down of the water surface is relatively small, and the distance the water level was lowered in all directions from the well was one-half mile or more. Recently pumping plants with capacity of 11 second-feet have been installed in 18-inch wells in sections having underground formations of this kind. Operation of these large pumps has shown that under the existing conditions perfect drainage may be accomplished at distances of more than a mile from the well without causing an excessive draw-down of the water surface in its immediate neighborhood. Thus fewer pumping plants are required, the cost of installing and operating the drainage system is less, and the maximum lowering of the water level is obtained where it is most needed.

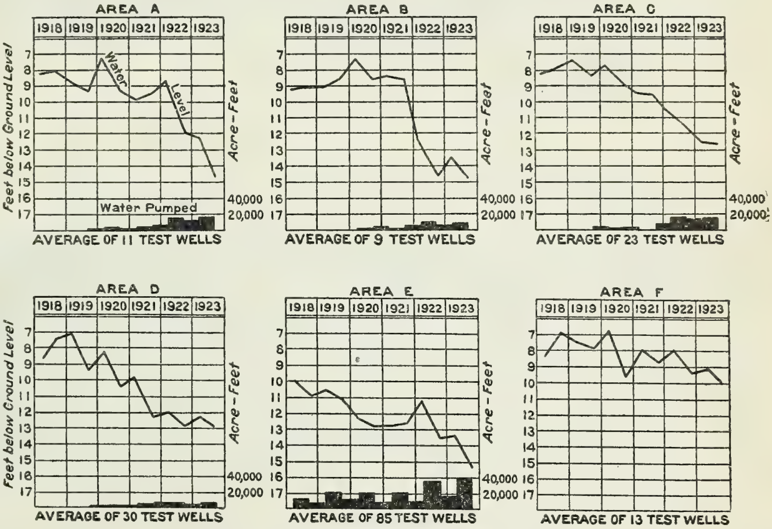


FIG. 12.—Curves showing ground-water level fluctuations in areas A, B, C, D, E, and F

An interesting comparison of the effectiveness of gravity drains with drainage by pumping from wells is afforded by the presence of the several closed gravity drains already described as forming a portion of the drainage system of the Salt River project, and by several deep open drains which cross certain areas adjoining the project.

The closed drain which at first constituted the only means of lowering the water level in area F was considered inadequate for that purpose, and pumping from wells has been resorted to as promising more desirable results. Table 3 shows the water levels at six test wells in October, 1920, just before the drain was constructed, and in October, 1923, when it had been in operation two years. These records show where water stood highest at the last regular time for making such observations, and represent conditions in the immediate vicinity of the drain. The locations of the test wells are shown in Figure 10.

TABLE 3.—*Highest water levels in area F, October, 1920, and October, 1923*

Location of test well	Depth to water October, 1920	Depth to water October, 1923
	Feet	*Feet*
S. ¼ corner sec. 8, T. 1 S., R. 2 E	3.0	3.1
W. ¼ corner sec. 9, T. 1 S., R. 2 E	[1] 3.8	4.7
NE. corner SE. ¼ SW. ¼ sec. 8, T. 1 S., R. 2 E	4.5	5.0
NW. corner SW. ¼ NE. ¼ sec. 9, T. 1 S., R. 2 E	2.8	5.0
N. ¼ corner sec. 9, T. 1 S., R 2 E	2.9	5.0
NW. corner SW. ¼ SW. ¼ sec. 9, T. 1 S., R. 2 E	4.3	6.0
Average	3.6	4.8

[1] Water level October, 1919, used for this well because the October, 1920, reading of 8 feet appears to be erroneous.

Hence between October, 1920, and October, 1923, the drain had effected a lowering of the water level of only 1.2 feet. The curve for this area shown in Figure 12, which is based on the records of 13 test wells, shows an even smaller drop in the water level between these two dates. The small improvement in this area has been due in part at least to the presence of a second deep open drain through lower lands outside the project but adjoining area F on the north. The bottom of this second drain is some 25 or 30 feet lower than the land surface in area F, thus affording an unusual depth of drainage for these lands.

A further indication that gravity ditches are not sufficiently effective wherever a thick stratum of relatively tight subsoil is encountered is present in the water-logged lands adjoining area E on the west. An open ditch about 7 miles long and averaging about 9 feet in depth was constructed through this district 10 years or more ago. A marked improvement in the productivity of soil in portions of this area has resulted, but landowners are not entirely satisfied with the results, and have requested that their farms be taken into the Salt River project in order to benefit from the effective drainage afforded by pumping from wells. It should be stated, however, that the drain referred to was never completed as original plans provided.

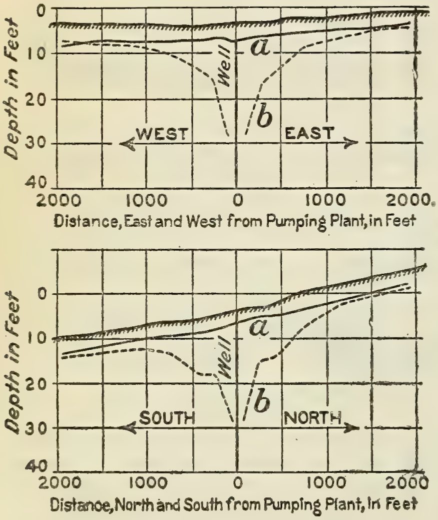
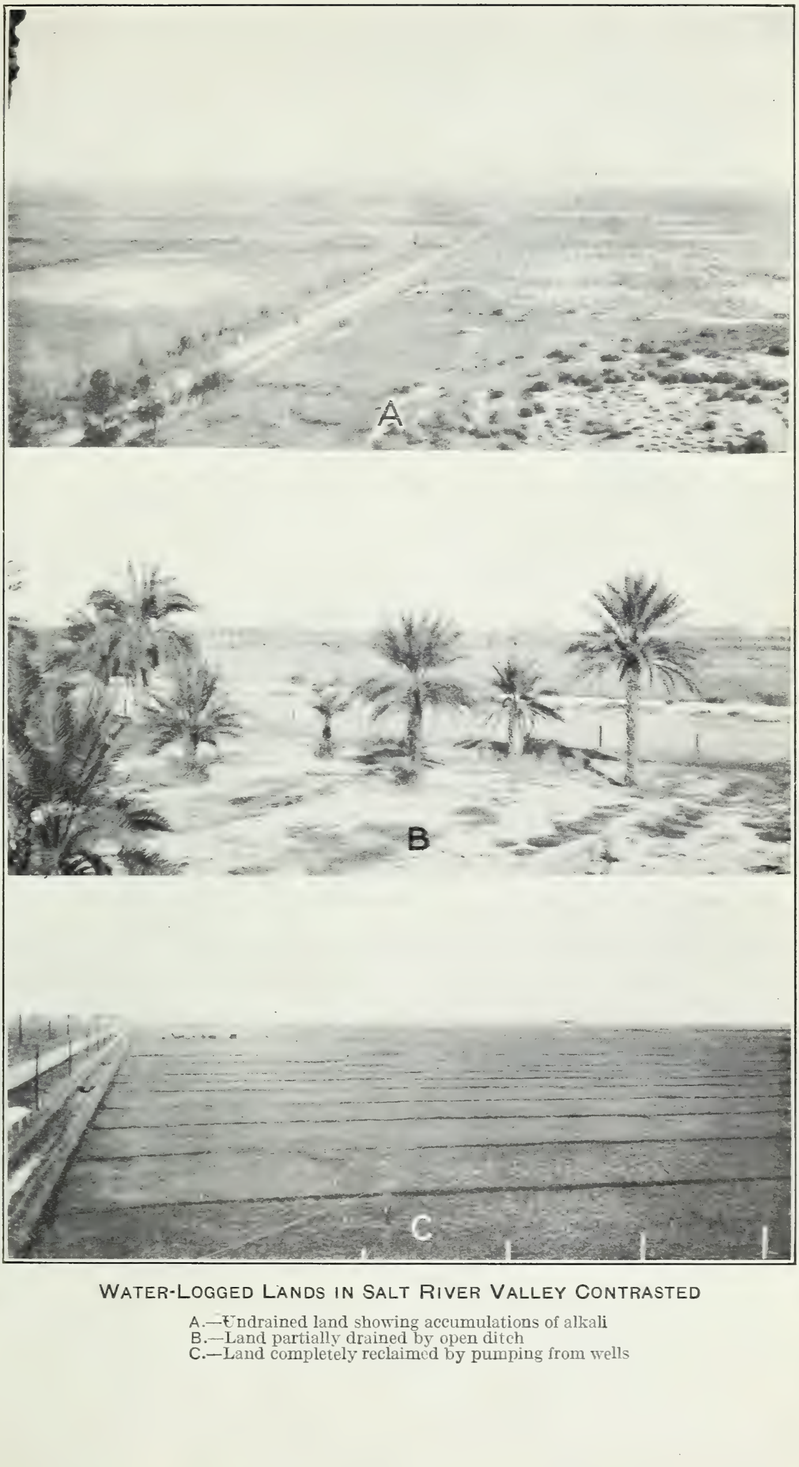


FIG. 13.—Fluctuations of water level surrounding pumping plant in area D

Plate 3 shows two recent views of lands in this area which are badly water-logged and damaged by alkali. The view shown as Plate

PLATE III



Water-Logged Lands in Salt River Valley Contrasted

A.—Undrained land showing accumulations of alkali
B.—Land partially drained by open ditch
C.—Land completely reclaimed by pumping from wells

3, A, was photographed from the northwest corner of section 29, T. 1 S., R. 4 E. The white spots are incrustations of alkali which resulted from the rise of ground water to within 18 inches of the surface. The view shown as Plate 3, B, was photographed from the northwest corner of section 3, T. 1 S., R. 4 E. The white line across the middle of this picture marks the west bank of the drainage ditch. Date palms, which appear in the foreground, are now the only useful vegetation that can survive in this alkali-infested spot. Plate 3, C, shows the contrast between conditions at places along this drain with that in area E, where pumping from wells has been the method of drainage. This picture was taken from the southeast corner of section 3, T. 1 S., R. 5 E., 6 miles east of the drain. Before the operation of the drainage pumps, land in this vicinity had been noticeably damaged by high ground water, but now it is adequately drained and fully reclaimed. Moreover, the closed drains in area D have not met with success equal to that attained elsewhere on the project by pumping from wells.

Drainage pumps have since been installed in area F and in the tract of land adjacent to area E, and the effect of their operation on lowering the ground-water level so far gives promise that satisfactory drainage will be accomplished by this means.

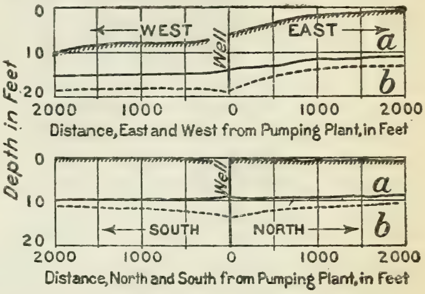


FIG. 14.—Fluctuations of water level surrounding pumping plant in area E

DRAINAGE RUN-OFF

The drainage run-off, or quantity of water that must be drained from soils of the Salt River project annually in order to give them desired protection, can not be estimated accurately at present. The water which has been removed from underground sources in recent years represents not only what has caused the ground-water level to rise, but in addition what had been stored in the soil above the present ground-water level.

The most dependable records of drainage run-off are those for the irrigated land included in areas A, B, C, and that portion of area D drained by the pumping method (fig. 1). The drainage pumps for all these areas were in operation from October 1, 1922 to September 30, 1923, except in a small portion of area D where six small drainage pumping plants have since been installed; they increase the capacity of the present drainage system for the four areas by about 4 per cent. During the 12 months ended September 30, 1923, 91,287 acre-feet of water was pumped from wells located in this portion of the project. For the entire gross area of irrigated land within the limits mentioned, this represents a drainage run-off of 0.65 second-foot per square mile, or the removal of 470 acre-feet of water from each square mile of contributing area per year. Considering only the 43,328 acres in the areas referred to the drainage run-off per square mile becomes 1.86 second-feet, or 1,348.4 acre-feet per square mile of affected area per year.

Run-off data for other portions of the project can not be determined accurately principally because of their close proximity to undrained or partially drained areas outside of the Salt River project.

COST OF THE DRAINAGE SYSTEM

The cost of the completed drainage system for the original area of the project is $1,056,157.97, distributed as follows: For pumping plants and power distribution system, $891,211.43; for closed drains in areas D and F, $75,115.19; for general drainage expense, $89,831.35. The total cost has been met by direct, flat assessments amounting to approximately $5.20 against each of the 203,000 acres of cultivated land now in the Salt River project. If the total initial cost were borne entirely by the 64,200 acres of gross land area classed as having ground water within 10 feet of the surface and as being in immediate need of drainage or drainage protection, it would amount to $16.45 per acre; and if charged against only those areas actually water-logged, it would be still higher.

Considering only that portion of the drainage system consisting of the 87 pumping plants operated during the 12 months ended September 30, 1923, the cost of developing drainage water has been at the rate of $2,904.82 per second-foot, this figure being reached by placing the cost of that portion of the drainage system at $940,000 and using the rated capacities of pumping plants as determined during September, 1923. (See Table 4.)

It is not possible to arrive at the cost of all the drainage pumping plants separately, nor to apportion the cost of the drainage system according to areas representing the different conditions in the Salt River project, since costs were not segregated in this manner for the earlier constructed plants. Where the wells are located in gravel and bowlder formations which readily give up large quantities of water, such as is the case in areas A, B, C, and E, the cost runs as low as $800 per second-foot of water, whereas in locations where there is little or no gravel, but fine formations that give up water slowly, a condition represented by areas D and F, the cost will run up to $5,000 per second-foot of water. The cost of such drainage upon an acre basis will vary to a less degree with these conditions, since less water will, in all probability, have to be removed from areas underlaid by tight formations than from those having extensive strata of gravel and bowlders.

Though these figures do not show the initial cost of drainage to be excessive, under more favorable conditions it might have been less. Most of the drainage system was installed during a period of high prices. With lower prices, the judicious plan followed in constructing the present system would effect a considerable reduction of the cost.

OPERATION AND MAINTENANCE COSTS

For the year ended September 30, 1923, the cost of the labor, materials, and electric power for the operation of 87 pumping plants was $59,524.58, or 29 cents per acre when applied to the entire project of 203,000 acres. The overhead and depreciation cost brings the total to $115,983.83, or 57 cents per acre. Six per cent interest on the initial cost of $1,056,157.97 (including the cost of the closed drains) makes the grand total for operation, maintenance, and fixed charges $179,353.31, or 88 cents per acre. If this cost is charged only to the area under which the ground water stood at 10 feet or less (approximately 64,200 acres), the cost per acre would be $0.93, $1.81, and $2.79, respectively.

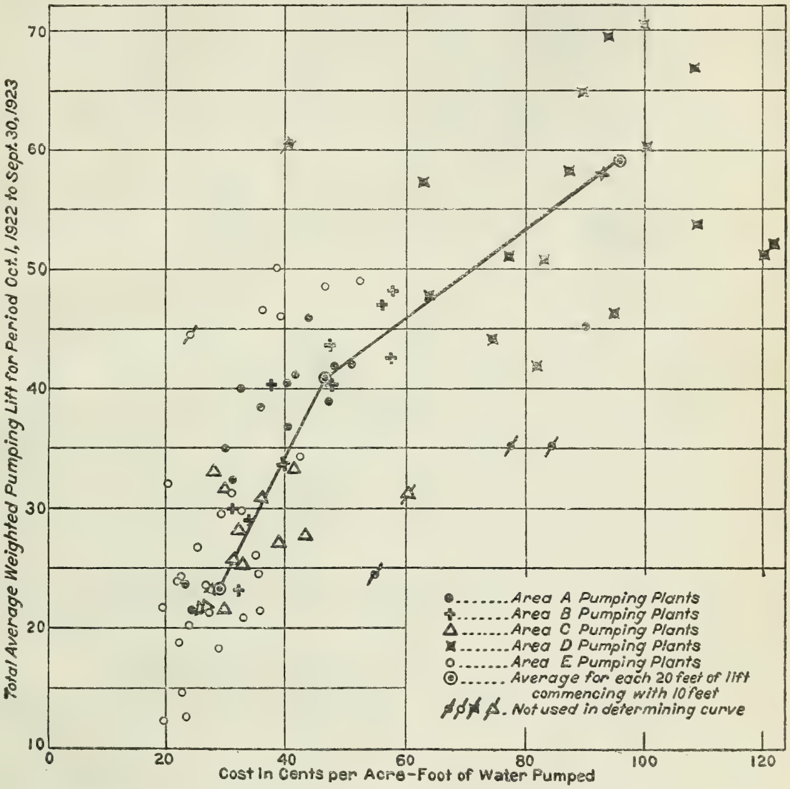


FIG. 15.—Cost of labor, material, and power per acre-foot of water pumped

Table 4 shows the costs of operating the individual pumping plants in the several areas where pumping from wells is employed. Figure 15 gives the cost of pumping water against the variable lifts.

Since these records are based upon the operation of the project when it was 89 per cent complete, and because the quantity of water pumped is subject to change by future drainage requirements, they may not apply to succeeding seasons.

It will be observed from Table 4 that the cost of electric current for operating the pumps is extremely low, comprising one of the most favorable features of the pumping plan of the Salt River project.

USE OF PUMPED DRAINAGE WATER FOR IRRIGATION

A little more than half of all water pumped from wells on the project during the season October 1, 1922–September 30, 1923, was used for irrigation. The remainder was wasted into natural streams, either because the cost of conveying it to lands upon which it could be used was too great, or because of its unsuitability for irrigation.

The drainage water used for irrigation is not distributed uniformly over the 203,000 acres of cultivated land in the project. Owing to the locations of the wells, pumped water can be delivered for irrigation use through only a few of the main canals and laterals. In these, it is the practice to mix drainage water with river water. Not over 25 per cent of the total quantity of water delivered for irrigation use is drainage water and in only one instance is so large a proportion of drainage water used.

The quality of this pumped water governs the degree to which it is being used for irrigation. In some wells the quantity of salts carried is higher than that usually considered allowable in irrigation water, and it is absorbed more rapidly and in greater quantities by the soil than is the case with river water.

There is a diversity of opinion as to the quantity of injurious alkali salts that may be permissible in water used for irrigation. It is generally conceded that water containing not more than 100 parts of these salts by weight per 100,000 parts of water may be so used safely; that is, upon evaporation of the water the weight of the solid material remaining should not exceed 0.1 per cent of the weight of the water evaporated. In some sections of the West water containing as much as twice this proportion of salts has been used without apparent injury to the crops irrigated. However, it has been the aim in the Salt River project to keep on the safe side in the use of the pumped water. A large number of analyses shows a variation in the actual quantity of alkali salts contained in water generally delivered to farms from a minimum of 35 parts per 100,000 parts of water to a maximum of 85 parts per 100,000, and the average for all the water used is 45 parts per 100,000.

The extraordinary degree to which the pumped water permeates the soils of the project has had a tendency first to decrease and then to increase demand for it. The relatively large quantity required for irrigation has discouraged its use unless mixed with a large portion of river water. On the other hand, there is a growing demand for it for leaching land which had become surcharged with alkali before installation of the drainage system. This is due to a general belief, which is not without support, that this water is particularly valuable for the reclamation of alkali lands, the calcium and magnesium salts carried by the water of most of the drainage wells having a tendency to make the soil more permeable, thus permitting a more rapid downward movement of water, which, of course, carries alkali with it.[1]

Aside from its value in draining the land, this method has justified its cost by reason of the value of the water for irrigation. The average initial cost of the drainage system was $2,904.82 per second-

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[1] SCOFIELD, CARL S. THE ALKALI PROBLEM IN IRRIGATION. Annual Report of the Smithsonian Institution, 1921, p. 220.

TABLE 4.-

Distance in miles east of principal meridian and north or south of Gila and Salt River base line	Wells			
	No.	Depth	Diameter	Pump

[1] F

7553°—26. (Face p. 21.)

foot. The average cost of labor, materials, and power for pumping 149,643 acre-feet of water from October 1, 1922, to September 30, 1923, was approximately 40 cents per acre-foot. It should be borne in mind, however, that the cost of this water varies for the several different conditions under which it is pumped, also that an attempt to duplicate these costs where economic conditions are not so favorable may prove disappointing.

The success of drainage by pumping in the Salt River Valley has induced other irrigation enterprises to undertake similar developments. Several such enterprises, although their records [illegible] not so long as those in the Salt River Valley, nevertheless serve to prove the practicability of this method of drainage. A few, in fact, have disclosed advantages not found in Salt River Valley, such as water having very low alkalinity and a possible greater flexibility in choice of location of pumps with reference to irrigated lands, permitting practically complete utilization of the pumped drainage water for irrigation. Hence, although the conditions in Salt River Valley are peculiarly adapted to pump drainage, it is possible that the success achieved there may be duplicated or even exceeded in many other irrigated sections.

TABLE 4.—*Description and cost of operating drainage pumping plants in Salt River Valley October 1, 1922–September 30, 1923*

	Wells			Pumping equipment			Operation for period Oct. 1, 1922, to Sept. 30, 1923													
Distance in miles east of principal meridian and north or south of Gila and Salt River base line	No.	Depth	Diameter	Pump	Electric motor		Average over-all efficiency	Capacity Sept. 1, 1923	Weighted average total lift	Water pumped during season	Power charge	Average power charge per kwh.	Cost of labor and materials	Cost of labor, materials, and power	Labor, materials, and power, cost per acre-foot	Labor, materials, and power, cost per acre-foot per foot lift	Charge for depreciation and overhead	Total costs for season	Total cost per acre-foot	Total cost per acre-foot per foot lift
					Make	Horsepower														
Area A																				
		Feet	*Inches*				*Per cent*	*c. f. s.*	*Feet*	*Acre-feet*										
2 E., 7 N	1	201	18	Layne Bowler, 18-inch, 3-stage.	Wagner	35	50.8	2.4	38.91	1,366	$398.41	$0.0036	$238.69	$637.10	$0.466	$0.012	$668.21	$1,305.31	$0.956	$0.025
2 E., 8 N	1	242	18	do	do	35	50.9	2.8	32.33	1,736	341.90	.0031	205.63	548.53	.316	.010	668.19	1,216.72	.701	.022
2 E., 9 N	1	232	18	do	do	35	54.3	2.3	40.38	1,376	321.56	.0030	235.15	556.71	.405	.010	668.17	1,224.88	.890	.022
3 E., 9 N	1	211	18	do	do	35	52.3	2.5	36.62	1,538	335.97	.0030	285.23	621.20	.404	.011	668.16	1,289.36	.838	.023
3 E., 10 N	1	240	18	do	do	35	53.8	2.3	40.93	1,202	271.27	.0028	227.84	499.11	.415	.010	668.16	1,167.27	.971	.024
3 E., 11½ N	1	290	18	Layne Bowler, 18-inch, 4-stage.	do	35	51.3	2.9	45.81	1,623	426.10	.0028	280.78	706.88	.436	.010	668.16	1,375.04	.847	.018
3 E., 12 N	1	190	18	Layne Bowler, 18-inch, 3-stage.	do	35	28.3	2.0	24.48	1,096	267.96	.0027	336.38	604.34	.551	.023	609.75	1,214.09	1.108	.045
3 E., 13 N	1	453	18	Layne Bowler, 18-inch, 4-stage.	do	25	44.2	2.5	45.06	1,469	384.09	.0028	942.21	1,326.30	.903	.020	668.15	1,994.45	1.358	.030
1 E., 7 N	1	206	18	do	Allis Chalmers	35	48.2	3.4	35.11	1,790	394.61	.0029	996.77	1,391.38	.777	.022	631.21	2,022.59	1.130	.032
1 E., 8 N	1	203	18	Layne Bowler, 18-inch, 3-stage.	Wagner	35	37.8	5.1	21.56	2,802	480.59	.0029	201.89	682.48	.244	.011	631.21	1,313.69	.469	.022
1 E., 9 N	1	198	18	do	do	35	42.8	5.2	23.81	2,877	497.24	.0029	180.97	678.21	.236	.010	631.21	1,309.42	.455	.019
1½ E., 10 N	1	207	18	do	Allis Chalmers	30	32.7	2.9	38.22	1,569	338.21	.0027	221.27	559.48	.357	.009	631.21	1,190.69	.759	.020
2 E., 10½ N	1	202	18	Layne Bowler, 18-inch, 4-stage.	do	30	47.7	3.2	35.08	1,660	345.47	.0026	1,060.62	1,406.09	.847	.024	631.20	2,037.29	1.227	.035
2 E., 11 N	1	202	18	do	do	30	51.5	2.9	39.66	1,584	334.18	.0027	180.78	514.96	.325	.008	631.20	1,146.16	.724	.018
2 E., 11½ N	1	225	18	do	do	35	50.5	3.0	41.97	1,503	353.18	.0027	417.16	770.34	.513	.012	631.20	1,401.54	.932	.022
2¾ E., 12 N	1	224	18	do	do	35	52.0	3.0	41.90	1,685	408.22	.0029	403.05	811.27	.481	.011	631.20	1,442.47	.856	.020
4 E., 12 N	1	277	18	Layne Bowler, 18-inch, 3-stage.	Wagner	35	50.8	4.1	34.48	2,628	593.45	.0032	194.54	787.99	.300	.009	631.20	1,419.19	.540	.016
Total and average	17	235						52.5	35.19	29,504	6,492.41	.0029	6,608.96	13,102.37	.444	.013	10,967.79	24,070.16	.816	.023
Area B																				
2 E., 6 N	1	483	18	Layne Bowler, 18-inch, 3-stage.	Wagner	35	49.0	2.9	30.0	1,739	342.22	.0030	203.23	545.45	.314	.010	667.25	1,212.70	.698	.023
3 E., 6 N	1	213	18	Layne Bowler, 18-inch, 4-stage.	Allis Chalmers	25	53.7	3.0	42.47	1,268	261.57	.0025	466.77	728.34	.574	.014	471.62	1,199.96	.946	.022
4 E., 6 N	1	220	18	Layne Bowler, 18-inch, 5-stage.	do	30	44.7	3.4	40.59	1,697	437.63	.0028	198.66	636.29	.375	.009	631.21	1,267.50	.747	.018
2 E., 5 N	1	345	18	Layne Bowler, 18-inch, 4-stage.	Wagner	35	47.1	2.4	40.87	1,661	494.75	.0033	295.90	790.65	.476	.012	662.04	1,452.69	.875	.021
3 E., 5 N	1	182	18	Layne Bowler, 18-inch, 3-stage.	do	35	51.0	2.3	33.71	1,242	278.91	.0029	216.41	495.32	.399	.012	607.06	1,102.38	.888	.026
4 E., 5 N	1	242	18	do	do	35	53.4	2.1	43.56	1,150	303.67	.0031	246.10	549.77	.474	.011	662.05	1,211.82	1.046	.024
5 E., 5 N	1	301	18	Layne Bowler, 16-inch, 5-stage.	do	35	43.8	1.5	48.21	939	329.85	.0031	213.66	543.51	.579	.012	662.06	1,205.57	1.284	.027
2 E., 4 N	1	203	18	Layne Bowler, 18-inch, 4-stage.	do	35	52.3	2.8	46.95	1,596	466.33	.0032	428.00	894.33	.560	.012	615.09	1,509.42	.946	.020
3 E., 4 N	1	211	18	Layne Bowler, 18-inch, 3-stage.	do	35	43.7	3.2	29.06	1,828	402.21	.0032	225.64	627.85	.343	.012	615.08	1,242.93	.680	.023
4 E., 4 N	1	150	18	Layne Bowler, 18-inch, 2-stage.	do	35	39.7	4.9	23.3	1,940	327.25	.0037	291.58	618.83	.320	.014	513.68	1,133.51	.584	.025
Total and average	10	253						28.5	36.78	15,069	3,645.09	.0030	2,786.25	6,431.34	.427	.012	6,107.14	12,538.48	.832	.023
Area C																				
7 E., 5 N	1	180	18	Layne Bowler, 18-inch, 3-stage.	Wagner	35	43.61	2.5	33.27	1,414.36	344.74	.0031	243.41	588.15	.416	.013	662.05	1,250.20	.884	.027
8 E., 5 N	1	264	18	do	do	35	44.8	2.7	30.78	1,530.80	327.47	.0031	224.37	551.84	.360	.012	662.05	1,213.89	.793	.026
9 E., 5 N	1	230	18	do	do	35	40.6	2.6	27.71	1,628.42	358.40	.0032	350.99	709.39	.436	.016	662.04	1,371.43	.842	.030
10 E., 5 N	1	141	18	do	do	35	33.9	3.7	27.10	2,030.39	522.06	.0031	269.67	791.73	.390	.014	662.04	1,453.77	.716	.026
11 E., 5 N	1	220	18	do	do	35	39.5	4.0	28.23	2,403.00	556.04	.0032	214.19	770.23	.325	.012	662.03	1,432.26	.596	.021
11½ E., 5 N	1	211	18	do	do	35	41.6	4.5	25.36	2,700.25	530.25	.0032	352.23	882.48	.327	.013	662.03	1,544.51	.572	.023
6 E., 2½ N	1	154	18	do	do	35	39.8	4.8	21.55	2,853.24	519.18	.0032	219.19	738.37	.259	.012	615.07	1,353.44	.474	.022
7 E., 3 N	1	150	18	Layne Bowler, 18-inch, 4-stage.	do	35	48.5	4.4	31.45	2,556.00	555.60	.0032	225.97	781.57	.306	.010	615.07	1,396.64	.546	.017
8 E., 3½ N	1	180	18	Layne Bowler, 16-inch, 3-stage.	do	35	27.5	5.0	21.59	2,769.71	524.14	.0032	299.61	823.75	.297	.014	615.07	1,438.82	.519	.024
9 E., 3½ N	1	152	18	do	do	35	40.2	4.6	23.36	3,053.20	612.80	.0034	225.09	837.89	.274	.012	615.06	1,452.95	.476	.020
10 E., 3¾ N	1	161	18	Kimball	Allis Chalmers	75	41.8	8.8	25.71	3,914.34	749.12	.0029	491.98	1,241.10	.317	.012	615.06	1,856.16	.474	.018
11 E., 3¾ N	1	182	18	Layne Bowler, 18-inch, 3-stage.	Wagner	35	39.3	4.0	21.44	2,854.07	516.88	.0033	222.99	739.87	.259	.012	615.06	1,354.93	.475	.022
11¾ E., 3¾ N	1	144	18	do	do	35	55.9	4.7	33.00	2,697.08	533.76	.0032	225.21	758.97	.281	.009	615.06	1,374.03	.509	.015
6 E., 5 N	1	320	18	do	do	35	48.2	2.7	31.37	1,570.00	330.09	.0031	630.20	960.29	.608	.019	662.06	1,622.35	1.027	.033
Total and average	14	190						59.0	26.59	33,983.86	6,980.53	.0030	4,195.10	11,175.63	.329	.012	8,939.75	20,115.38	.592	.022
Area D																				
12 E., 9 N	1	470	18	Layne Bowler, 12-inch, 2-stage.	United States Electric	20	35.4	1.4	47.74	880.73	389.30	.0032	172.46	561.76	.638	.013	659.06	1,220.82	1.386	.029
13 E., 9 N	1	484	18	Layne Bowler, 18-inch, 4-stage.	Wagner	35	69.9	2.5	60.19	1,565.28	426.78	.0031	229.20	655.98	.419	.007	659.08	1,315.06	.840	.014
13½ E., 8¾ N	1	285	24	Layne Bowler, 24-inch, 2-stage.	General Electric	25	49.9	1.6	68.21	938.44	356.82	.0032	227.96	584.78	.623	.011	659.07	1,243.85	1.325	.023
14 E., 9 N	1	345	18	Layne Bowler, 16-inch, 6-stage.	Allis Chalmers	25	50.4	1.5	53.64	1,025.72	354.18	.0032	762.02	1,116.20	1.088	.020	659.07	1,775.27	1.731	.032
15 E., 9 N	1	225	18	Layne Bowler, 12-inch, 2-stage.	United States Electric	10	31.5	.4	51.21	303.30	158.96	.0030	207.78	366.74	1.209	.024	659.08	1,025.82	3.382	.066
15 E., 8½ N	1	219	12	do	do	20	32.4	.9	57.93	553.04	321.27	.0032	191.05	512.32	.926	.016	555.27	1,067.59	1.930	.033
15 E., 8 N	1	190	12	do	do	20	34.8	1.0	61.10	614.24	318.77	.0032	275.27	624.14	1.016	.017	555.26	1,179.40	1.920	.031
16 E., 8 N	1	246	12	do	do	25	30.1	1.4	41.83	758.88	372.47	.0032	249.12	621.59	.819	.020	555.26	1,176.85	1.551	.037
16 E., 7½ N	1	290	12	do	do	20	28.3	.9	43.97	821.25	421.38	.0032	188.18	609.56	.742	.017	555.25	1,164.81	1.418	.032
17 E., 8 N	1	205	12	do	do	20	32.4	1.1	51.01	777.19	394.23	.0032	204.65	598.88	.771	.015	555.25	1,154.13	1.485	.029
17 E., 7½ N	1	226	12	do	do	20	29.9	1.1	50.76	662.06	368.76	.0032	180.06	548.82	.829	.016	555.24	1,104.06	1.668	.033
18 E., 7½ N	1	165	12	Layne Bowler, 12-inch, 3-stage.	do	20	35.9	.8	70.53	502.13	319.49	.0031	179.85	499.34	.994	.014	555.23	1,054.57	2.100	.030
18½ E., 7½ N	1	265	12	Layne Bowler, 12-inch, 2-stage.	do	20	35.8	.9	58.24	499.85	262.26	.0032	174.81	437.07	.874	.015	555.23	992.30	1.985	.034
19 E., 7¾ N	1	150	12	Layne Bowler, 12-inch, 3-stage.	do	20	25.5	.7	51.98	372.77	287.66	.0029	168.25	455.91	1.223	.024	464.43	920.34	2.469	.047
12 E., 8½ N	1	262	16	Byron Jackson, 12-inch, 2-stage.	do	20	30.9	1.3	46.19	713.00	291.30	.0025	386.71	678.01	.951	.021	364.49	1,042.50	1.462	.032
13 E., 8½ N	1	253	16	do	do	20	37.1	1.0	69.22	607.29	371.36	.0032	196.96	568.32	.936	.014	396.15	964.47	1.588	.023
14 E., 8½ N	1	271	16	do	do	20	35.2	1.0	66.96	520.38	300.90	.0030	262.30	563.20	1.082	.016	362.40	925.60	1.779	.027
13 E., 10 N	1	242	16	do	do	20	34.4	1.0	64.73	621.00	376.56	.0031	160.94	537.50	.898	.014	396.15	933.65	1.536	.024
12 E., 10N	1	200	12	Kimball pumps in small sizes.																
12½ E., 10 N	1	200	12																	
13½ E., 9½ N	1	[1] 201	12																	
14½ E., 8½ N	1	79	12																	
17½ E., 7 N	1	202	12																	
18½ E., 7 N	1	172	12																	
Total and average	24	241						20.5	55.43	12,736.58	6,122.45	.0031	4,437.67	10,560.12	.829	.015	9,720.97	20,281.09	1.592	.029
Area E																				
27 E., 7 S	3	[2] 810	16	Byron Jackson, 12-inch, special.	Wagner	75	47.0	8.0	49.0	2,282	617.48	.0026	572.63	1,190.11	.522	.011	1,075.05	2,265.16	.993	.020
28 E., 6½ S	3	[2] 851	16	do	do	75	50.2	8.2	46.0	2,549	579.44	.0024	429.84	1,009.28	.396	.009	1,319.04	2,328.32	.913	.020
26 E., 6 S	3	676	16	do	do	75	58.5	9.8	48.4	2,762	529.19	.0023	761.62	1,290.81	.467	.010	1,094.02	2,384.83	.863	.018
28 E., 3½ S	3	[2] 773	16	do	do	75	55.5	8.0	48.5	2,293	457.06	.0023	375.38	832.44	.363	.008	1,246.52	2,078.96	.906	.019
26 E., 4 S	3	[2] 662	16	do	do	75	70.0	11.2	44.5	2,102	325.53	.0024	177.91	503.44	.240	.005	539.76	1,043.20	.496	.011
26 E., 3½ S	3	[2] 663	16	do	do	75	55.5	10.0	32.0	2,015	295.11	.0024	110.23	405.34	.201	.006	422.12	827.46	.411	.013
8 E., 1 N	5	2,153	12	Byron Jackson, 12-24-inch, special.	do	75	56.3	10.0	50.0	3,426	796.80	.0025	550.26	1,347.06	.393	.008	1,279.95	2,627.01	.767	.015
25 E., 2 S	5	1,060	12	Krogh horizontal, 14-inch	General Electric	100	32.0	11.0	31.3	3,405	745.08	.0022	335.10	1,080.18	.317	.010	532.90	1,613.08	.474	.015
27 E., 1 N	1	130	18	Layne Bowler 18-inch, 3-stage.	Wagner	35	27.9	2.6	18.56	1,178	191.50	.0024	147.93	339.43	.288	.016	549.66	889.09	.755	.041
29 E., 1 N	1	253	18	do	do	35	48.3	3.5	20.32	1,543	216.10	.0027	155.92	372.02	.241	.012	603.89	975.91	.632	.031
25 E., 0 N	1	152	18	do	do	35	41.5	3.3	21.44	1,400	205.52	.0027	297.39	502.91	.359	.017	669.51	1,172.42	.837	.039
26 E., 0 N	1	160	18	do	do	35	37.0	2.7	24.57	1,157	217.60	.0027	192.43	410.03	.354	.014	669.51	1,079.54	.933	.038
27 E., 0 N	1	161	18	do	do	35	51.5	3.5	26.77	1,600	229.56	.0027	182.38	411.94	.257	.010	669.51	1,081.45	.676	.025
28 E., 0 N	1	172	18	do	do	35	39.4	2.3	34.21	1,039	257.24	.0027	184.43	441.67	.425	.012	669.50	1,111.17	1.069	.031
29 E., 0 S	1	180	18	do	do	35	43.1	2.6	29.67	1,225	230.67	.0027	170.86	401.53	.328	.011	603.86	1,005.39	.821	.028
25 E., 1 S	1	162	18	Layne Bowler, 18-inch, 2-stage.	do	35	36.6	4.0	12.38	1,947	173.46	.0026	211.61	385.07	.198	.010	494.60	879.67	.452	.036
26 E., 1 S	1	167	18	do	do	35	26.5	3.3	12.65	1,451	168.99	.0026	174.77	343.76	.237	.019	494.57	838.33	.578	.046
27 E., 1 S	1	182	18	Layne Bowler, 18-inch, 3-stage	do	35	40.0	3.6	21.39	1,707	242.85	.0026	222.92	465.77	.273	.013	494.60	960.37	.563	.026
28 E., 1 S	1	175	18	Layne Bowler, 18-inch, 2-stage.	do	35	42.4	2.9	18.97	1,384	165.43	.0026	143.27	308.70	.223	.012	494.58	803.28	.580	.031
29 E., 1 S	1	154	18	Layne Bowler, 18-inch, 3-stage.	do	35	26.5	3.5	14.65	1,610	237.32	.0026	125.11	362.43	.225	.015	494.57	857.00	.532	.036
26 E., 2 S	1	162	18	do	do	35	39.9	3.7	22.75	1,260	166.73	.0022	124.35	291.08	.231	.010	494.57	785.65	.624	.027
27 E., 2 S	1	160	18	Layne Bowler, 18-inch, 4-stage.	do	35	40.2	3.6	24.19	1,390	198.31	.0022	125.11	323.42	.231	.010	494.57	817.99	.585	.024
28 E., 2 S	1	160	18	Layne Bowler, 18-inch, 3-stage.	do	35	44.2	3.4	23.87	1,317	164.35	.0022	125.12	289.47	.220	.009	494.57	784.04	.595	.025
23 E., 4½ S., ¼ W	1	170	18	Worthington, 18-inch, 3-stage.	Allis Chalmers	60	42.3	7.9	23.41	5,215	1,014.32	.0034	393.49	1,407.81	.270	.012	677.57	2,085.38	.400	.017
24 E., 4 S	1	246	18	Layne Bowler, 18-inch, 3-stage.	Wagner	35	35.8	5.1	20.96	2,929	590.61	.0033	394.50	985.11	.336	.016	677.56	1,662.67	.568	.027
24 E., 5 S	1	236	18	Worthington	Allis Chalmers	75	45.9	10.2	20.17	2,232	530.96	.0033	261.89	792.85	.355	.014	475.00	1,267.85	.568	.022
25 E., 5 S	1	245	18	Worthington, 18-inch, 3-stage.	do	75	45.8	9.2	29.37	4,350	895.89	.0031	373.38	1,269.27	.292	.010	677.54	1,946.81	.448	.015
22 E., 5½ S	1	184	18	Kimball	do	75														
25 E., 6½ S	1	183	18	Kimball, 18-inch	do	75														
Total and average	49	212						157.1	30.33	56,779	10,443.10	.0027	7,319.83	17,762.93	.313	.010	18,409.10	36,172.03	.637	.021
Area F and Miscellaneous Areas																				
18 E., 2½ N	6	864	16	Krogh		100	29.8	6.0	30.0	1,571	304.93	.0023	187.26	492.19	.313	.010			1.787	.060
22½ E., 6 N	1	151	20	Byron Jackson, 18-inch, 4-stage.	Allis Chalmers	75														
8½ E., 1¼ S	1	202	12	Kimball																
8 E., 1¾ S	1	201	12	do																
7½ E., 2¼ S	1	201	12	do																
Total and average	10	162						6.0	30.0	1,571	304.93	.0023	187.26	492.19	.313	.010	2,314.50	2,806.69	1.787	.060
All Areas																				
Total and average	124	226						323.6	33.21	149,643.44	33,988.51	.0025	25,534.77	59,524.58	.398	.012	56,459.25	115,983.83	.775	.023

[1] Final depth of this well is 201 feet.

[2] Depth of all wells in each battery.

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December 6, 1926

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